NBSIR 77-1399

Performance of A Water-Thinned Polyurethane Seamless Flooring System

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Center for Building Technology
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ABSTRACT

This paper summarizes the work of a two-year project to evaluate the performance of a recently developed flooring system. The flooring system is a water-thinned polyurethane system proposed for use in high traffic areas. The use of water as a solvent was intended to relieve occupants of dwellings and applicators of seamless flooring systems of the danger of exposure to toxic solvents and the discomfort of eye and skin irritants during installation. The goals of this project were:

1. To evaluate by laboratory tests and field demonstrations the performance and durability characteristics of a water-thinned polyurethane seamless flooring system.
2. To compare the performance of a water-thinned polyurethane system with solvent-thinned polyurethane systems and other conventional flooring materials.
3. To recommend performance criteria for the selection of water-thinned polyurethane seamless flooring systems.

The project was divided into two phases. In the first phase, laboratory evaluation, conventional and modified methods of standard tests were used to determine the level of performance of this newly developed system and to characterize its durability under simulated in-service conditions. Laboratory testing also provided for comparison of the performance of the new system with that of conventional seamless flooring systems.

In the second phase of the project, field demonstration, performance of the system was observed under in-service conditions. Demonstration of the system at 20 sites in various parts of the country, provided many facets of in-service conditions under which flooring materials must perform. In addition, it permitted NBS personnel and local housing engineers to observe and record in-service performance of the systems. This phase of the project was especially beneficial in that local housing maintenance engineers, knowledgeable about the performance of conventional flooring materials and skilled in their maintenance, had an opportunity to evaluate the system under in-service conditions. Data obtained from local maintenance engineers at the 20 demonstration sites confirmed laboratory findings that the system did not compare favorably with conventional seamless flooring systems for use in high traffic areas.

Key Words: Water-thinned polyurethane system; solvent-thinned polyurethane system; vinyl tile; laboratory findings; field demonstration; maintenance engineers; service conditions; high-traffic areas.

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SI CONVERSION UNITS

In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, the metric SI system of units have been used throughout this publication. However, in view of the present accepted practice of using common U.S. units of measurement for building technology in this country, appropriate conversion factors have been provided in the table below. The reader interested in making further use of the system of SI units is referred to:

NBS SP330, 1977 Edition, "The International System of Units"
NBS 380-76 ASTM Metric Practice Guide (American National Standard Z210.1)

The conversion factors for the units found in this report are as follows:

Length

1 in = 0.0254 meter* (m)

1 ft = 0.3048 meter* (m)

Area

1 in^2 = 0.000645 square meter S(m^2)

1 ft^2 = 0.0929 square meter (m^2)

Mass

1 lb = 0.453 kilogram (kg)

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*Exactly

Temperature

degree celsius $t°C = 5/9(t°F - 32)$

Pressure

1 psi = 6895 pascal (pa)

Mass/Time (Flow)

1 perm (23°C) = 5.745×10^{-11} kilogram/pascal second meter^2

(kg/Pa s m^2)

Energy

1 inch - pound - force (in-lbf) = 0.1130 joule

1.0 Introduction

During the past twenty years, solvent-thinned polyurethane systems have been used extensively for seamless flooring in high-traffic areas of public buildings.[1/*] A typical polyurethane system consists of a primer or basecoat, an intermediate coat, vinyl chips and a clear glaze coat. Traditionally, these systems have been used in bathrooms, kitchens, laundry rooms and hallways. These areas require floor finishes with high impact, stain, abrasion and mar resistance. In many cases polyurethane systems are impermeable membranes for sealing porous surfaces and for retarding the transfer of water and water vapor. In brief, the solvent-thinned polyurethane flooring systems are versatile, functional and durable. However, developing concurrently with the use of the solvent-thinned polyurethane systems has been an awareness of their unpleasant odor and irritant nature. This has created a demand in the flooring industry for information and education on the hazards and safeguards relating to the solvents used in these flooring systems.

Engineers in the Department of Housing and Urban Development (HUD) indicated a need for a flooring system equal in performance to the solvent-thinned polyurethane system, yet free of unpleasant odors and irritating solvents. A response to this need was the development of a polyurethane system using water as a solvent instead of organic solvent. This system was intended to retain the properties of the conventional solvent-thinned systems while relieving occupants and applicators of exposure to toxic and irritating solvents. At HUD's request, NBS personnel have conducted an evaluation of this newly-developed system.

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*Numbers represent references given at the end of this report.

1.1 Background

The purpose of this investigation was to collect and evaluate data concerning the service performance of a water-thinned polyurethane seamless flooring system and to develop performance criteria for selection of such systems. The system was intended for use in high-traffic areas of public housing which may be frequently soiled and subjected to impact and abrasion through occupant use. This report on the performance of the newly developed system under laboratory and in-service conditions is intended to be a guide for those engaged in the design, specification and purchase of such materials.

This project included a laboratory evaluation of the properties of the water-thinned polyurethane system and a comparison of those properties with more conventional seamless flooring materials. In addition, the laboratory evaluation was complemented by evaluating the system at 20 demonstration sites in 10 HUD regions in various parts of the United States. This in-service evaluation included field inspections at four selected sites by NBS personnel and monitoring by local maintenance engineers at each of the sites. Concisely, the objectives of this project were:

1. To evaluate by laboratory tests and field demonstrations the performance and durability characteristics of a water-thinned polyurethane seamless flooring system.

2. To compare the performance of a water-thinned polyurethane system with solvent-thinned polyurethane systems and other conventional flooring materials.

3. To recommend performance criteria for the selection of water-thinned polyurethane seamless flooring systems.

1.2 Approach

The project was conducted in two parts: 1) Laboratory evaluation, and 2), Field demonstration.

1.2.1 Laboratory Evaluation

The water-thinned polyurethane system was evaluated in the laboratory to establish its levels of performance in selected tests. The following approach was used to identify those properties evaluated:

1. The purpose for which the material was to be used was defined and the service conditions were characterized.

2. Technical data on related materials for similar use were reviewed and samples selected for comparison.

3. Suitable accelerated tests were identified to evaluate properties related to user requirements and service conditions.

As a result of the above considerations, a list of properties believed to be important to the performance of a flooring material in public housing was drawn up (see Table 1).

1.2.2 Field Demonstration

In-use observation of the performance and durability of the new flooring system was an essential part of the evaluation. For that reason, the polyurethane flooring system was applied at 20 sites (see Table 2) in 10 HUD regions of the United States. NBS personnel coordinated the application of the system at the various sites, assisted local housing maintenance engineers in the gathering of data, and made periodic on-site inspections at four selected sites. The 20 sites provided a variety of substrates to which the system was applied; revealed the effect of various environmental conditions and the performance of the system in several locations of different buildings.

Table 1. Desirable Properties of Conventional Flooring Materials for Use in Public and Private Buildings

Property	Requirement
Resistance to abrasion	High
Film integrity	High
Resistance to impact	High
Resistance to indentation	High
Dimensional stability	High
Resistance to solar radiation	High
Resistance to water vapor	High
Resistance to stain	High
Flame spread	Low
Smoke generation	Low

Table 2 Demonstration Sites for the Water-Thinned Polyurethane Seamless Flooring System

1. Toledo, Ohio
2. Jeannette, Pennsylvania
3. Chester, Pennsylvania
4. Charleston, South Carolina
5. Birmingham, Alabama
6. Biloxi, Mississippi
7. New Orleans, Louisana
8. San Antonio, Texas
9. Little Rock, Arkansas
10. Phoenix, Arizona
11. San Francisco, California
12. Tacoma, Washington
13. Denver, Colorado
14. Kansas City, Missouri
15. Superior, Wisconsin
16. Chicago, Illinois
17. Detroit, Michigan
18. Boston, Massachusetts
19. Camden, New Jersey
20. Newark, New Jersey

2.0 Laboratory Evaluation

2.1 Materials

2.1.1 Water-Thinned Polyurethane System

At the beginning of this project, the water-thinned polyurethane system to be evaluated (see Table 3), was a new material which had limited use as a flooring material. It was the only known commercially available water-thinned system; however, at least one other water-thinned polyurethane flooring system has become commercially available during the course of this investigation. For purposes of characterization and future reference, the infra-red spectrum of the water-thinned polyurethane glaze coat is shown in Appendix A. A time-base thermogram of the complete system is shown in Appendix B.

2.1.2 Solvent-Thinned Polyurethane Systems (Comparison Samples)

Two solvent-thinned polyurethane seamless flooring systems (see Table 3) which had been studied in a previous investigation [2] were used for comparison purposes. Hereinafter, data given for the solvent-thinned system are an average of these two systems.

2.1.3 Vinyl Tile

The vinyl tile (see Table 3) selected as a comparison sample, is a widely used vinyl tile comforming to Federal Specification SS-T-312, Type III.

Table 3 Test and Comparison Samples

Water-Thinned Polyurethane Systems (Components)

A. Epoxy base coat (water-thinned)

B. Epoxy intermediate coat (same as in A)

C. Vinyl chips

D. Urethane top coat

Solvent-Thinned Polyurethane Systems (Components)

1. A. Epoxy base coat

   B. Epoxy intermediate coat

   C. Vinyl chips

   D. Urethane top coat

2. A. Epoxy base coat

   B. Urethane top coat

Vinyl Tile

Vinyl tile conforming to
Federal Specification SST-312, Type III

2.2 Preparation of Specimens

2.2.1 Seamless Flooring Systems

The preparation of each seamless flooring system followed the procedure recommended by the manufacturer. Specimens were prepared on two substrates:

1. Steel panels, Type R, Q panels (0.875 mm x 150 mm x 300 mm) cold rolled, low carbon steel (ASTM D609, Type 1-B).

2. Plywood, (19 mm x 609 mm x 609 mm) conforming to Exterior AC Grade, Species Group 1 (American National Standard A199.1-1974, Voluntary Product Standard PS 1-74).

After preparation, specimens were cured for seven days at 23 ± 2°C and 50 ± 5% rh unless specified otherwise. Smaller specimens as required for specific tests were made from these panels. Where free films of the seamless flooring systems were required, a 0.075 mm film of polyethylene was used as a release agent. The polyethylene was affixed to the plywood board by a vinyl adhesive prior to application of the seamless flooring system. After the seamless flooring system had cured for 7 days, the system was peeled from the polyethylene as a free film.

2.2.2 Vinyl Floor Tile

Where necessary to satisfy a test requirement, vinyl tile was affixed to plywood and metal panels (2.2.1) by adhesive as recommended by the manufacturer.

2.3 Test Methods and Results

Tests were chosen to measure those physical properties which are directly related to the performance of flooring materials. Test methods and procedures were intended to simulate conditions encountered in use in public and private housing. The data obtained is presented below and the tests are referenced in the interim performance criteria of Section 5. The properties considered to be of greatest importance for the intended application of water-thinned seamless flooring systems were identified and evaluated as outlined below.

2.3.1 Abrasion Resistance

Flooring systems for high-traffic areas must resist wear and retain their integrity during abrasion under heavy pedestrian traffic.

The abrasion resistance test was performed as described in Method 6192 of Federal Test Method Standard No. 141a [3]. Triplicate specimens (100 mm x 100 mm) were taken from prepared steel panels (2.2) and drilled with a center hole (6.25 mm). For each abrasion resistance determination, a load of 1000 gm and abrasive calibrase wheels, No. CS-17, were used with a Taber Abraser* (Figure 1). Specimens were abraded for 1000 cycles and the weight loss was recorded to 0.1 mg.

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*Identification of commercial products is included only to adequately specify the procedure. Identification does not imply recommendation or endorsement by the National Bureau of Standards.

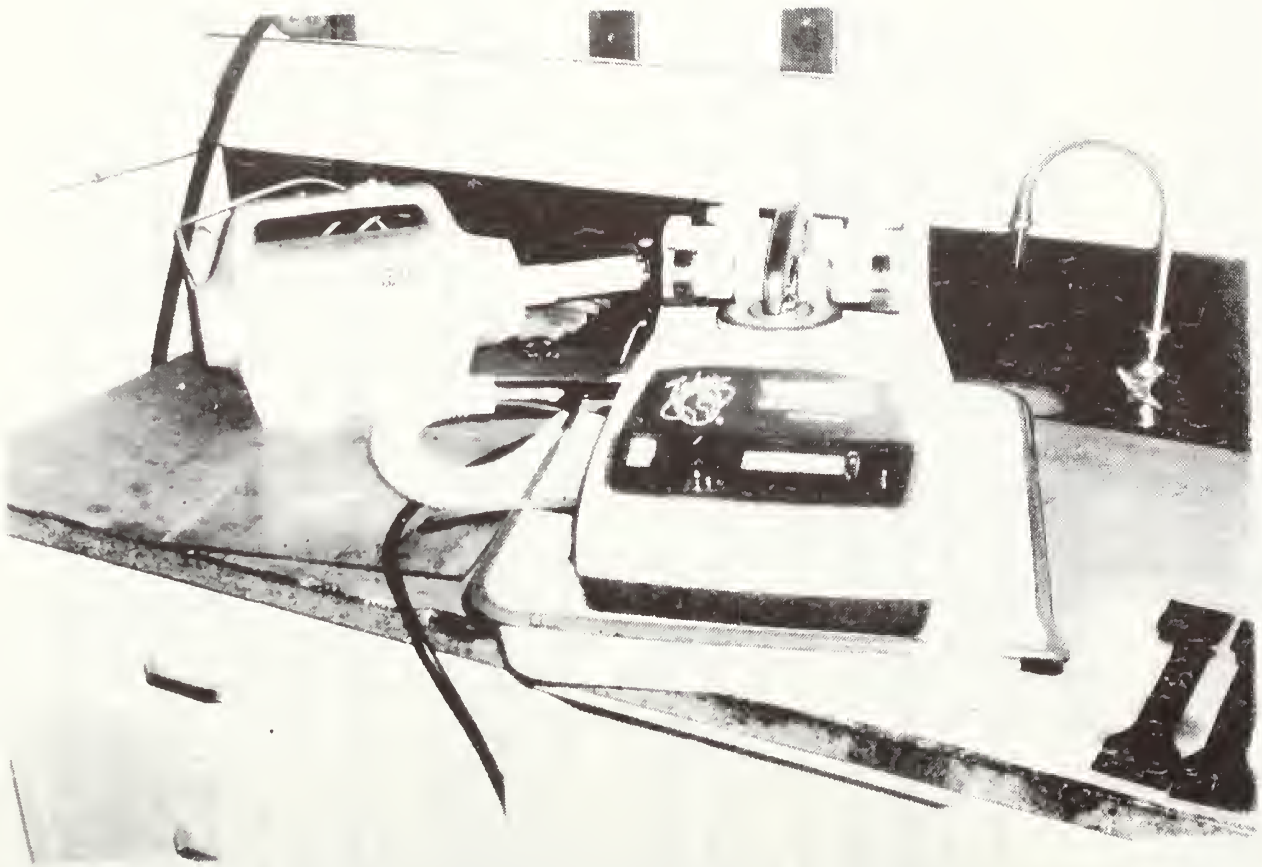

Figure 1. Abrasion Test Apparatus With Abraser Wheels Being Refaced On An Abrasive Disc.

2.3.2 Film Integrity

2.3.2.1 Tensile Strength

Tensile strength is of primary importance in any material that may be subjected to stress and strain during service. The purpose of this test was to determine the maximum load, in kilograms, and the total elongation, in millimeters, up to the breaking point of the flooring systems while increasing the strain at a constant rate.

Tensile strength measurements were made with a universal testing machine on free films of the systems. Specimens were prepared as outlined in Section 2.2 except that the plywood board was coated with polyethylene. Specimens were cut into a "dogbone" shape (25.4 mm wide and 254.0 mm long) by die and removed as free films. Triplicate specimens of vinyl tile were cut from squares of tile without substrate backing. The thickness of each specimen was measured with a dial gauge to the nearest 0.0025 mm.

The basic test method was as outlined in ASTM D882, Method B. The specimen was mounted in the testing machine equipped with serrated grips at a gauge length of 177.8 mm. Then the specimen was subjected to tensile test at a crosshead speed of 5.0 mm/min. The tensile test continued until a maximum load was obtained. Tensile strength was calculated by dividing the maximum load in kilograms by the original minimum cross-sectional area in square millimeters. The average strengths are reported for three specimens of each sample. The results are shown in Table 4.

Table 4 shows that the tensile strength of the water-thinned system was 11.8 megapascals. This value is considerably lower than the 34.3 megapascals for the solvent-thinned systems and 73.5 megapascals for the vinyl tile.

2.3.2.2 Elongation

Flooring materials require a moderate amount of elongation for keeping stresses generated during service at relatively low levels. The purpose of this test is to determine how much a flooring system may be extended without losing its integrity.

While the specimens were being tested for tensile strength as specified above, the elongation was measured to the moment of rupture. The percent elongation was calculated by dividing the elongation at the moment of rupture by the original length and multiplying by 100.

Results of the determinations are seen in Table 4. The percent elongation of the water-thinned system (1.7%) is considerably lower than either the solvent-thinned system (3.3%) and vinyl tile (5.6%).

2.3.3 Impact Resistance

Flooring systems for use in high-traffic areas must resist the effects of dragged, thrown or dropped objects. The purpose of this test was to determine the system's resistance to cracking, chipping, flaking and delamination under impact.

Impact resistance was determined as described in ASTM D 2794, Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). Triplicate specimens (100 mm x 100 mm) were taken from prepared steel panels (2.2) and impacted with a 0.9070 kilogram cylindrical impact weight. The tests were performed with the coated side up. The largest number of Joules at which failure (cracks around the perimeter of the indentation) did not occur was determined.

Results of the impact tests are shown in Table 4. The impact before failure of the water-thinned polyurethane system was 7.7 joules. The impact before failure of the solvent-thinned polyurethane and vinyl tile was 9.0 joules.

2.3.4 Indentation (Loading)

The ability of a flooring system to resist the effects of loading is due in-part to its density and thickness. Flooring systems in a high-traffic area of public housing must resist indentation from loading by heavy appliances and over-loaded chairs, tables and desks.

The apparatus used in this test was a hydraulic press. This method of test consisted in permitting a load increased in increments of 6.4×10^4 pascals to act for specific periods of time (five minutes) upon a flooring system on steel panels (2.2). The force was applied through the flat-end of a cylinder having a head area of 6.5×10^{-4} m^2. The test panel rested on a steel platen and was removed after application of successive increments of force and inspected for indentation. The failure load was that load required to produce a visible impression under the cylinder.

Table 4 shows the minimum loads required to make an indentation in the three flooring systems. Indentation due to loading occurs at approximately 8.2×10^5 pascals for the water-thinned polyurethane system; the solvent-thinned system indents at approximately 11.7×10^5 pascals and the vinyl tile at approximately 13.1×10^5 pascals.

2.3.5 Dimensional Stability

The ability of a seamless flooring system to resist movement (flow or slip) due to temperature changes depends on its cohesive strength and strength of bond to the substrate. The purpose of this test was to determine the extent of movement when the system was exposed to relatively high temperatures.

Flow or slip was determined as described in 4.7.5.1 of Military Specification D-3134F. Triplicate specimens (150 mm x 150 mm) of the flooring systems were cut from steel panels (2.2), scribed, and placed vertically in an oven at 70°C for five hours. The difference between the distances from the scribed mark to the reference edge before and

after heating is a measure of flow or slip. The measurements were made by suitable calipers to the nearest 0.0025 mm under the prescribed test conditions.

The movement (see Table 4), shown by the water-thinned polyurethane system was 0.015 mm. Movements of the vinyl tile and solvent-thinned polyurethane system were 0.003 and 0.004 mm, respectively.

2.3.6 Resistance to Solar Radiation

Seamless flooring systems for use in areas exposed to sunlight must resist solar radiation. Exposures to sunlight near windows and in vestibules and other entrances may result in significant local changes in color, and cause localized aging. The purpose of this test was to determine the effects of solar radiation on the flooring systems.

Resistance to solar radiation was determined by exposing the flooring systems to a xenon-arc radiant energy source in a weathering machine equipped with a constant wattage transformer to operate a 6500 watt water-cooled lamp. The lamp contained an inner and outer cylinder of borosilicate glass which filtered out all wave lengths below 290 nanometers and above 1300 nanometers.

Triplicate specimens (100 mm x 100 mm) were taken from the plywood panel (2.2) after curing for seven days. To determine color change, the color of each specimen was measured before exposure with a color difference meter. Specimens were then exposed to solar radiation at a black box temperature of 67 ± 2°C. After 24 hours, the specimens were removed and stored at 23 ± 2°C for two hours. Again, the color of each specimen was determined, and the color change calculated as specified in Method 6123 of Federal Test Method Standard 141a. Specimens were also inspected for cracking, checking and peeling.

Color changes resulting from exposure in the xenon-arc weathering machine are presented in Table 4. The greatest change occurred in the vinyl tile, whereas the water-thinned system showed the least change.

2.3.7 Resistance to Water Vapor

In order for finish coats of flooring materials to remain protective, decorative and functional, they must not be easily penetrated or dissolved by water, dirt, dust and water vapor. The purpose of this test was to determine the resistance of the finish-coat to the penetration of water vapor.

The basic test method used is described in ASTM-E 96. Duplicate specimens are prepared by application of the glaze coat, by draw-down, to the highly permeable portion of penetration chart forms* at a wet film thickness of 0.250 mm. The specimens were then cured for seven days at 23 ± 2°C and 50 ± 5% rh.

A disc (100 mm in diameter), cut from the chart with the cured film, was sealed over the mouth of a permeability cup containing a desiccant, and placed in an atmosphere of 23 ± 2°C and 50 ± 5% rh. The assembly was weighed once every twenty four hours, and the results for the period in which the gain in weight was linear with time were used to calculate the rate, in kilogram/pascal-second-meter^2 ($kg/pa \cdot s \cdot m^2$), of water vapor movement through the membrane.

The permeabilities of the two glazed coats were 4.6×10^{-11} $kg/pa \cdot s \cdot m^2$ for the solvent-thinned system and 1.2×10^{-10} $kg/pa \cdot s \cdot m^2$ for the water-thinned system (see Table 4).

*Charts (Form HK) may be obtained from the Leneta Company, P.O. Box 675, Ho-Ho-Kus, New Jersey.

Table 4 Comparative Performance of Three Flooring Systems

Property	System: Water-Thinned Polyurethane	System: Solvent-Thinned Polyurethane	System: Vinyl Tile
Abrasion, weight loss (1000 g load/1000 cycles, mg)	150	55	33
Color change (solar radiation for 24 hours, ΔE)	0.2	1.9	5.0
Color change (water and high temperature, ΔE)	4.0	5.0	2.3
Dimensional stability, flow (70°C for 5 hours, mm)	0.015	0.004	0.003
Elongation (maximum % for original length)	1.7	3.2	5.6
Impact (resistance to rupture (joules)	7	9	9
Indentation (by loading, pascals)	8.2×10^5	11.7×10^5	13.1×10^5
Water vapor permeance (glaze coat, $kg/pa \cdot s \cdot m^2$)	1.2×10^{-10}	4.6×10^{-11}	N.A.
Tensile strength (megapascals)	11.8	34.3	73.5

2.3.8 Stain Resistance

The appearance of a floor is often the greatest single factor determining its useful life. To be useful, a flooring system must resist the effects of shoe markings and exposure to common household cleaners.

Stain resistance of the flooring systems was, generally, determined as described in ASTM D 1308, Effect of Household Chemicals on Clear and Pigmented Organic Finishes. Glass vials (25.4 mm I.D., 12.7 mm height) were sealed to the surface of the flooring systems with a polyurethane sealer. After 24 hours, 1 ml of the stain (see Table 5) was placed in the sealed ring and covered with a watch glass. Marks by felt-tip pen were similarly covered. Sixteen hours later the watch glasses were removed, the stains washed off and alteration to the surface noted.

Table 5 identified the effect of each of seven stains on the three flooring systems. The water-thinned polyurethane system was discolored by four of the stains; vinyl tile was discolored by three, and the solvent-thinned system was discolored only by one. The tendency of the water-thinned polyurethane system to re-emulsify under standing water would be a significant drawback in its use in high-traffic areas.

Table 5   Effects of Household Stains on Three Flooring Systems

SYSTEM	Coffee	Mustard	Tea	Shoe Polish	Mercuro-chrome	Felt-Tip Pen	Water
Water-Thinned	stains	no effect	stains	no effect	stains	no effect	temporary whitening; appearance recovered on drying
Solvent-Thinned	no effect	no effect	no effect	no effect	stains	no effect	no effect
Vinyl Tile	no effect	very slight stain	no effect	stains	no effect	stains	no effect

2.3.9 Flame Spread*

Interior finishes in residences are recognized as contributors to fire deaths. For this reason, it is advisable to characterize all new and innovative materials for their contribution to flame spread. The purpose of this test was to determine the surface flammability of the water-thinned polyurethane flooring system.

The flame spread test method used was ASTM E-162, "A Standard Method of Test for Surface Flammability of Materials Using A Radiant Heat Energy Source" [4]. Test specimens were prepared on plywood board as outlined in section 2.2. Flame spread tests determine a flame spread index number which reflects the rate of flame propagation over the surface of the material.

An inclined 150 mm x 450 mm specimen of the material is situated in front of a radiant heat source (300 mm x 450 mm panel). Ignition is induced near the upper edge and the flame front progresses downward. A factor derived from the rate of progress of the flame front (ignition properties) and another relating to the rate of heat liberation by the material under test are combined to provide a flame spread index.

As shown in Table 6, the average flame spread value for the water-thinned polyurethane system was 416. Published reports [5], [6] revealed flame spread values of 70 and 129 for vinyl tiles; 200 and 240 for solvent-thinned polyurethane systems.

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*Testing conducted by Program for Fire Control Construction, National Bureau of Standards Center for Fire Research.

Table 6 Flame Spread Value of a
Water-Thinned Polyurethane Flooring System

Specimen No.	Polyurethane Coating Thickness mm	Plywood Thickness mm	Measured Density kg/m^3	Flame Spread* Fs	Q	Is
1	0.78	18.76	592.7	19.62	20.3	398
2	0.78	18.75	592.7	23.74	19.2	437
						416 Avg.

*
Fs = Flame spread factor

Q = Heat evolution factor

I_s = Flame spread index

2.3.10 Smoke Generation*

The smoke generated by an interior finish should be a primary consideration in assessing life safety of the interior of a dwelling. The purpose of this test was to determine the smoke generation characteristics of the water-thinned polyurethane flooring system.

The smoke generation test method used is described in NBS TN 708, "Interlaboratory Evaluation of the Smoke Density Chamber Test Method", Appendix II, by T.G. Lee, December 1971 [7]. Test specimens were prepared in 28 mm by 75 mm by 75 mm size on 19 mm AC Grade, Species Group I plywood. The system was subjected to smoke generation tests by measuring the progressive attenuation of a light beam passed through the smoke aerosol within the enclosed smoke chamber. The smoke level is reported in terms of specific optical density, a dimensionless attenuation coefficient which defines the amount of smoke accumulated from a specimen of unit surface area in terms of its photometric obscuration over unit path length within a chamber of unit volume [7]. The test consists of a thermal irradiation exposure of 2.5×10^4 W/m^2 normal to the exterior surface of the test specimen, and was performed under both flaming and nonflaming (smoldering) conditions. To induce open flaming, a small pilot natural gas diffusion flame is applied at the base of the specimen.

Specific optical density, Ds, is a property of a specimen of given thickness, and represents the optical density measured over unit path length (L), within a chamber of unit volume (V), produced from a specimen of unit surface area (A). Thus:

$$Ds = D\left(\frac{V}{AL}\right) = \frac{V}{AL}\left[\log \frac{100}{T}\right]$$

*Testing Conducted by Program for Fire Control Construction Center for Fire Research, National Bureau of Standards, Center for Fire Research.

where T = percent light transmission, and D is normally referred to as "optical density." For the test chamber, $V = 5.0 \times 10^{-1} m^3$, $A = 4.2 \times 10^{-3} m^2$, and $L = 9.0 \times 10^{-1} m$. The change in Ds with time depends only on the thickness of the specimen, its chemical and physical properties and exposure conditions [7].

In the testing of flooring, the complete system and underlayment were tested. This procedure was followed because the underlayment has been found to have a significant effect upon small scale test results for flooring.

Test results indicated that the specimens produced more smoke in the non-flaming mode than in the flaming mode, and that the optical density (smoke) levels were still increasing at the end of the twenty minute test duration in two of the tests (see Table 7). Several gaseous components and their concentration in parts per million are also given in Table 7.

3.0 Field Demonstration

Although the laboratory tests discussed in the foregoing sections may give information on the physical characteristics of flooring systems, and the uniformity of a particular sample, they cannot predict the performance of any one system under all possible conditions of service life. Therefore, where possible, it is advantageous to test the performance of the systems in service.

HUD officials, in concurrence with local housing authorities, selected twenty sites for application of the water-thinned system for in-service tests. At least one site (see Table 2) was located in each of the ten HUD regions throughout the country. Selection of the particular dwellings was fortuitous in that it provided for application of the system over the following common substrates: 1) asphalt tile, 2) concrete, 3) wood, 4) vinyl asbestos tile, and 5) vinyl tile. Application of the system at the twenty sites was carried out by a

Table 7 Results of Smoke Generation Test on Water-Thinned Polyurethane Systems.

Sample	Thickness mm	Measured Density kg /m^3	Exposure F=Flaming N=Non-flaming	Maximum Specific Optical Density D_m(CORR.)	Indicated Gas Concentration (Time, Min.) PPM HCL	HCN	NO+NO_2	SO_2	CO	WT. Loss %
Water-Thinned Polyurethane Seamless Flooring on 12.5 mm Plywood	13.3	557	F	126↑	(20)14	(21)10	(22)35	(23)20	(24)2,500	17.5
			F	235						15.5
			F	163	(8) 4	(11) 6	(12)30	(13)15	(18)2,800	14.8
			Avg.	176						15.9
			N	467						11.7
			N	505						12.4
			N	494						11.6
			Avg.	489↑						11.9

NOTE: (↑) Indicates smoke levels were still increasing at the end of the twenty minute test duration.

professional applicator who was well established in the seamless flooring industry, and who had experience in application of the water-thinned seamless flooring system.

A record of the application and performance of the system was obtained from the maintenance engineer at each of the twenty sites. This data was supplemented by on-site inspections at four of the sites by NBS personnel. The evaluations by local housing maintenance engineers were very important because they are experienced in floor maintenance and familiar with the needs of the tenants. The format shown in Table 8 was used by both, NBS personnel and local maintenance engineers to evaluate the system.

3.1 Preparation of Substrate

The average time required to prepare the substrate at each of the twenty sites was four and one-half hours. This included one employee skilled in the application of seamless flooring systems and one helper provided by the local housing authority. Typical equipment involved a mechanical sander, putty knife, broom and mop. Degreasing and wax cleaners were also available. The average area coated ranged from 42 to 47 $meters^2$. Typical substrate preparation procedures are shown in Figure 2. The failure most frequently noted in this phase of the program was an uneven substrate which later showed through the system.

3.2 Application of the System

Application of the system was by a skilled applicator assisted by the local housing maintenance employee. The average application time, including a drying time of about two hours between coats, was twenty hours. Application equipment included a mixer, vacuum cleaner, trowel, brush, roller and three pairs of shoes - including one pair of golfing shoes which provided minimal adhesion to the applied system (see Figures 3-5).

Figure 2 Preparation of Substrate Using Heavy Duty Sander

Figure 3 Casting and Leveling of Vinyl Flakes

Figure 4 Addition of Vinyl Flakes to Attain Desired Decorative Pattern and Subsequent Overcoat by Glaze Coat.

Figure 5 Removal of Excess Vinyl Flakes

The skill of the applicator was reflected in the number of vertically protruding chips. Horizontal arrangement of the chips is due, in part, to the skill of the applicator in applying the glaze coat. Protruding chips frequently inhibit pedestrian foot movement and contribute to uncomfortable walking conditions.

The major shortcoming of the system evident from this phase of the program was the number of glaze coats required to obtain adequate wearing thickness. A minimum of three glaze coats was applied at each site. The manufacturer's "Approved Application Method" is included in Appendix C [8].

3.3 Inspections by NBS Personnel

Through arrangements by officials of the Department of Housing and Urban Development, and with the cooperation of the local housing authorities, field inspections were made at sites in the following cities:

1. Boston, Massachusetts
2. Camden, New Jersey
3. Chester, Pennsylvania
4. Newark, New Jersey

At each site, discussions were held with staff and field engineers on 1) preparation of the substrate; 2) application of the system; 3) performance of the systems; and 4) comparison of the performance of the system with the performance of other flooring materials.

3.3.1 Preparation of Substrate

1. Preparation of the substrate is critical
2. The preparation process is laborious and tedious
3. Average preparation time for 42 to 47 $meters^2$ was 4.5 hours
4. Equipment required:
    a. heavy duty sanding machine,

b. commerical vacuum cleaner,

c. mixer, and

d. three pairs of shoes, including one pair of golfing shoes.

3.3.2 Application Process

1. Base coat may be brushed, rolled or troweled.
2. Application time, including two hours drying time between coats, was approximately twenty hours for $46.5m^2$.
3. Several coats of glaze coat were required to provide an adequate wearing thickness.
4. Good ventilation was required during application and drying of the system.
5. Although the system was thinned with water, an unpleasant odor presisted.
6. Surface preparation, application and curing of the system required a minimum of four-day occupant vacancy.
7. Chips occasionally protruded above the glaze coat.

3.3.3 Appearance of System

1. The gloss was low, a higher gloss was desired.
2. Overall appearance of the system was good.
3. An outline of irregularities in the substrate showed in several locations ("telegraphing").
4. At least one high spot was visible at each site.

3.3.4 Appearance After Six Months

1. Stains were noted.
2. A cigarette burn was evident.
3. Changes in color of the system were noted.
4. Chips protruded in several spots.

3.3.5 Appearance After Ten Months

1. Discoloration was evident.
2. Dusting of the finish was observed.
3. Numerous stains were noted (see Figures 6-9).
4. Abrasion was evident in high-traffic areas.
5. Several indentations were noted.
6. Overall appearance was judged fair to poor.
7. Dirt was embedded in the surface of the system.

3.3.6 Maintenance

1. Required daily sweeping because of tendency to dust.
2. Stained easily.
3. Stains were difficult to remove.

Data obtained from on-site inspections by NBS personnel were similar to those recorded in laboratory tests and reinforced the conclusion, drawn from laboratory tests, that the water-thinned polyurethane system was not suitable for use in high-traffic areas. Major factors contributing to this conclusion were the system's tendency to: stain; indent; wear; embed dirt; and discolor.

3.4 Evaluation by Local Maintenance Engineers

The local maintenance engineers at the twenty demonstration sites contributed much to the evaluation of the water-thinned system. Their responses to contacts by phone and periodic questionaires provided current information on the performance of the system at each site. After ten months, a final questionaire was forwarded to the engineer at each of the twenty sites. Of the twenty forms forwarded, eighteen were returned. A summary of the final assessments provided by the local engineers is shown in Table 8.

Figure 6 Cigarette Burn and Chemical Staining of the Water-Thinned Polyurethane System

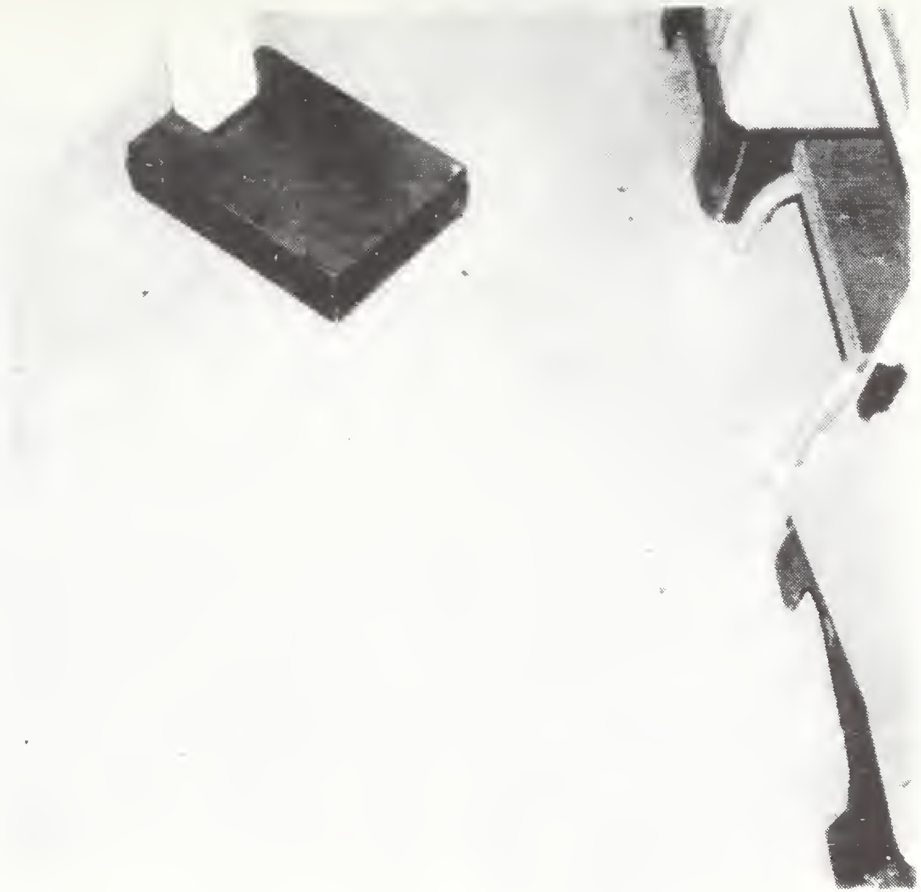

Figure 7 Multiple Staining of the Water-Thinned Polyurethane System

Figure 8 Solvent and Rust Staining of the Water-Thinned Polyurethane System

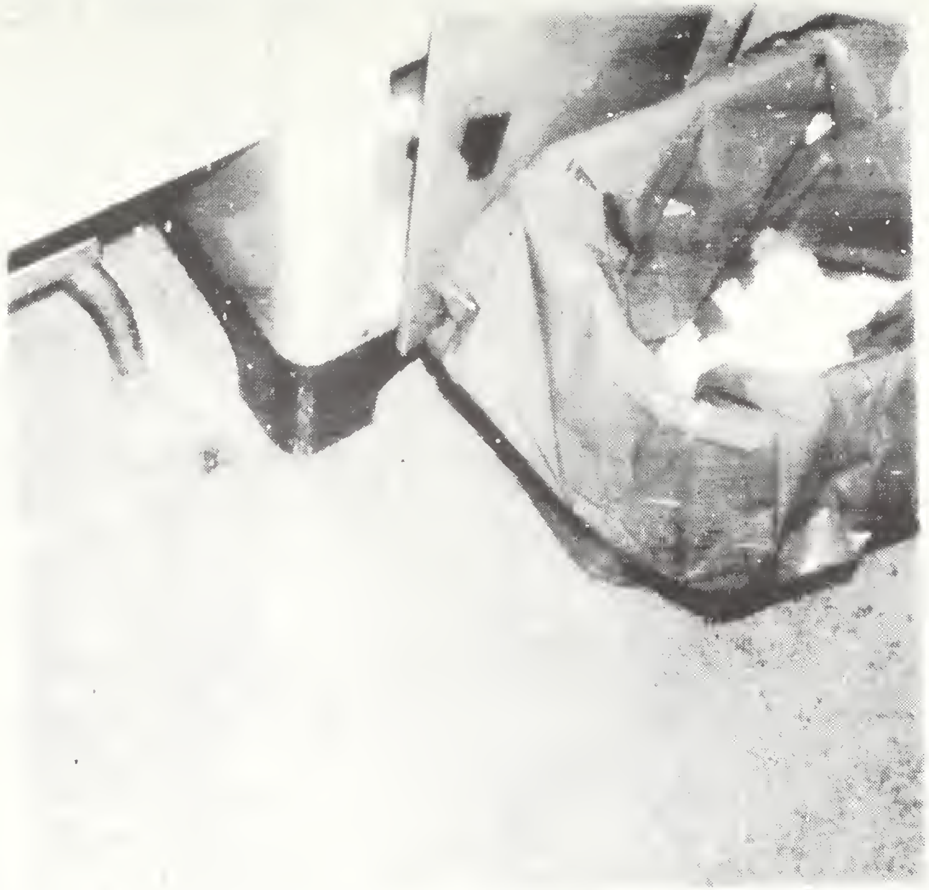

Figure 9 Furniture Staining and Indentation of the Water-Thinned Polyurethane System

Table 8 Evaluation of the Water-Thinned System After 10 Months Service by Engineers at 18 of the 20 Demonstration Sites.

	Appearance	Percentage*
1.	Overall appearance	
	Good	38
	Fair	50
		16**
2.	Discolored	
	Yes	42
	No	48
		16
3.	Uniform gloss	
	Yes	57
	No	28
		15
4.	Embedded dirt	
	Yes	64
	No	36
		18
5.	Worn	
	Yes	29
	No	71
		18
6.	Telegraphing of substrate	
	Yes	21
	No	79
		18
7.	Cracks	
	Yes	20
	No	80
		18
8.	Shrinkage	
	Yes	14
	No	86
		18
9.	Uniform color	
	Yes	79
	No	21
		18
10.	Lifting from substrate	
	Yes	24
	No	76
		18

*Percentage of 18 respondents who rated the system as shown.

**Total number responding to this issue.

Table 8 (continued)

Service	Percentage
1. Sweeping required	
Daily	86
Weekly	0
Other	0
	16
2. Waxing required	
Daily	0
Weekly	20
Other	0
	4
3. Dirt removed	
Easily	42
Not so easily	58
	18
Comparison with more conventional flooring materials (e.g., tile, linoleum, and solvent seamless systems)	
1. Water-thinned seamless systems	
Preferred	20
Not preferred	80
	18
2. Wears	
Faster	27
Slower	20
Same	40
	16
3. Stains	
More easily	40
Less easily	27
Same	0
	12
4. Requires more maintenance	
Yes	53
No	15
Same	0
	12
5. Discolors more readily	
Yes	40
No	20
Same	0
	11
6. Indents more easily	
Yes	63
No	33
Same	0
	17

Table 8 (continued)

Service	Percentage
1. Rough to walk on	
Yes	7
No	93
	18
2. Protruding Chips	
Yes	14
No	86
	18
3. High spots	
Yes	7
No	93
	18
4. Wear resistance	
Good	57
Fair	29
Poor	14
	18
5. Stains	
Few	54
Several	21
None	20
	17
6. Indents	
Yes	64
No	36
	18
7. Scuffs	
Heel marks	29
Furniture movement	57
	16
8. Water spots	
Yes	14
No	86
	18
9. Obvious color change	
Yes	29
No	71
	18
10. Other comments	
Would not recommend for use in heavy traffic areas	40
	7

Table 8 (continued)

Service	Percentage
7. Retains buff more easily	
Yes	27
No	47
Same	13
	16
8. Scuffs more easily	
Yes	53
No	27
	14
9. More suitable for needs of tenants of public housing	
Yes	27
No	40
Same	20
	16

In reviewing this table, it should be kept in mind that the system had been in use for a relatively short period of time (ten months). This represents only a small fraction of the intended service life (approximately 8 years) of the flooring system. Exemplary in-service performance in the test sites would have been an essential requirement for acceptance as a system for use in high-traffic areas. This was not the case, 80 percent of the engineers who evaluated the system in the field preferred more conventional types of flooring systems. Other characteristics that were not in the satisfactory range, as judged by a majority of the engineers, were: 1) embedded dirt, 2) stains, 3) indentations, 4) maintenance requirements, 5) scuffs, and 6) dirt was difficult to remove. These observations of the in-service performance of the system was consistent with the conclusions based on the laboratory results (see Table 9). Thus the flooring cannot be considered suitable for use in high-traffic areas such as those in which it was tested.

4.0 Summary of Properties and Recommendations

Laboratory evaluations, visits to field demonstration sites and assessments by field engineers were used to determine the suitability of a water-thinned polyurethane flooring system for use in high-traffic areas of public housing.

Laboratory tests were used to determine values of performance-related properties by subjecting the sample to simulated in-use conditions. These tests relied upon a close following of visual changes and measurement of physical alterations within the system. These physical changes were readily detected and measured. Similar tests were carried out on solvent-thinned polyurethane systems and vinyl tile. It was concluded:

1. The water-thinned polyurethane flooring system is not suitable for use in high-traffic areas.

Table 9

Correlation Between Laboratory Tests and Field Performance of the Water-Thinned Polyurethane Seamless Flooring System

Property	Laboratory Findings	Field Performance
Abrasion Resistance	Low resistance to wear	* Twenty-nine percent reported worn appearance.
Tensile Strength	"Low"	Twenty percent indicated crack formations.
Stain Resistance	"Low"	Fifty-four percent reported staining of system.
Indentation	"Low resistance to indentation"	Sixty-four percent reported mar by indentation.
Dimensional Stability	"Subject to dimensional changes"	Fourteen percent reported shrinkage.
Water Vapor Performance (Porosity)	"Subject to penetration by water, dirt, water vapor"	Sixty-four percent reported embedded dirt.
Suitability for use in high-traffic areas	"Not suitable"	Eighty percent reported conventional system preferred.

* Percentage of 18 respondents who rated the system as shown.

2. The performance of the water-thinned system, as determined by laboratory evaluation, correlated well with on-site evaluations at 20 demonstration sites.
3. The weight loss of the water-thinned system when abraded by a Taber Abrader was greater than the solvent-thinned polyurethane system and vinyl tile.
4. The tensile strength of the water-thinned polyurethane was least of the flooring materials tested.
5. The elongation of the water-thinned polyurethane system was considerably less than either the solvent-thinned system or the vinyl tile.
6. Exposure of the water-thinned system to seven household materials resulted in severe staining.
7. The maximum impact before the water-thinned system cracked was less than either the vinyl tile or the solvent-thinned polyurethane system.
8. The water-thinned polyurethane system indented at a considerably lower force than either the vinyl tile or the solvent-thinned polyurethane system.
9. The water-thinned polyurethane showed a greater tendency to flow than either the solvent-thinned system or the vinyl tile.
10. The vinyl tile showed the greatest change in color due to solar radiation, the water-thinned polyurethane the least.
11. The water vapor permeance of the glaze coat of the water-thinned polyurethane system was considerably higher than that of the solvent-thinned polyurethane system.
12. The flame spread index of the water-thinned system was greater than that reported in the literature for conventional vinyl tile.

As a result of the foregoing evaluations, properties of the water-thinned polyurethane system were further compiled and summarized as follow:

Property	Characteristic
Abrasion resistance	Low
Tensile strength	Low
Impact resistance	Low
Indentation	Low indentation resistance
Resistance to staining	Low
Permeability	Subject to penetration by water and water vapor.

The above characteristics were confirmed in field inspections of four sites, and by HUD maintenance engineers at 18 of the 20 sites where the system was applied. For example, evidence of wear, stain, indentation, color change, and embedded dirt were observed at the four sites. Other problems such as the long occupant-vacancy time required for application of the system were noted. Many engineers and tenants expressed a desire for a higher gloss finish, and remarked about the number of glaze coats required. At least three applications of the glaze coat were required. Thus, the cost-benefit of the system is affected adversely by the number of glaze coats necessary to obtain sufficient thickness to provide adequate wear resistance. Another observation was the pungent odor during application of the system. In many cases, forced ventilation was used.

Evaluations by engineers and other staff members at the various sites confirmed laboratory and field inspection findings. Eighty two percent of those who made the final evaluation preferred other flooring materials to the water-thinned system.

Past histories have shown solvent-thinned polyurethane seamless flooring systems and vinyl tiles to perform well in the use for which the water-thinned flooring was being considered. Therefore, these two systems were selected as comparison samples. Thus, reasonable criteria of acceptance of the water-thinned flooring are that it should meet or exceed the performance levels of the other two types of flooring in appropriate laboratory tests. Since in most laboratory tests, it fell far short of the level of performance for the solvent-thinned polyurethane seamless flooring and vinyl tile, the water-thinned flooring did not appear to be an adequate substitute for the other types. However, it was desirable to assure by field tests that this conclusion was not due to laboratory tests having been set at unreasonable high levels.

Although data indicate that the water-thinned system is not the most suitable flooring material for high-traffic areas, it may be adequate for other applications such as wall coatings in bathrooms, hallways, recreational and food service areas.

5.0 Recommended Interim Criteria for Water-Thinned Polyurethane Systems

Laboratory test results presented in Section 2 and data obtained from in-service performance provide the basis for the following interim criteria for water-thinned polyurethane systems for use in high-traffic areas. Water-thinned polyurethane systems for use in high-traffic areas should perform as well or better than the comparison floor samples evaluated in this report. On that basis, the following criteria were developed. The criteria are preliminary and may need to be updated as additional information becomes available.

5.1 Resistance to Abrasion

Requirement

Flooring systems should have long service life even when exposed to abrasion from heavy pedestrian traffic.

Criterion

When tested as outlined below, the average weight loss of triplicate specimens shall not exceed 55 milligrams.

Test

Triplicate specimens are prepared by applying the system to 100 x 100 mm solvent-cleaned No. 21 gauge cold rolled steel according to the manufacturer's directions. The system is cured for seven days at 23 $\pm$ 2°C and 50 $\pm$ 5% rh. Then a 6.25 mm diameter hole is drilled in the center of each steel square to permit mounting in the abrasion tester.

The initial weight of each square specimen is determined to the nearest milligram and the specimens are mounted as directed in Method 6192 of Federal Test Method Standard 141a. Using CS 17 calibrase wheels with a load of 1000 grams on each wheel, the specimen is abraded for 1000 cycles, and its weight loss determined.

Commentary

Flooring systems are subjected to abrasion from occupant traffic. Flooring systems intended for use in high-traffic areas should be highly resistant to wear.

The expression of abrasion resistance as milligrams of weight loss per number of cycles establishes a meaningful comparison by which flooring systems can be rated. The system evaluated in this report would not be rated suitable for use in high-traffic areas.

5.2 Film Integrity

Requirement

Flooring systems should be able to resist the stress and strain of pedestrian traffic and environmental changes during their service life. They should remain intact under stresses expected in service.

Criterion 1 - Tensile Strength

When tested as outlined below, the average tensile strength of triplicate specimens shall not be less than 34.3 mega pascals.

Test

The basic test method shall be as outlined in ASTM-D882, Method B. Specimens are prepared by applying the coating according to the manufacturer's instructions to a plywood board coated with polyethylene. Specimens are cut into a "dogbone" shape (25.4 mm wide and 254.0 mm long) by die and removed as free films. The thickness of each specimen is measured with a dial gauge to the nearest 0.001 mm.

The specimen is next mounted in the testing machine equipped with serrated grips at a gauge length of 177.8 mm. Then the specimen is subjected to tensile test at a crosshead speed of 5.0 mm/min. The tensile test continues until a maximum load is obtained. Tensile strength is calculated by dividing the maximum load in kilograms by the original minimum cross-sectional area in square millimeters. The average strengths are reported for three specimens of each sample.

Commentary

This test is designed to determine the tensile properties of various flooring systems. Good tensile strength is of basic importance in any material that may be subjected to stress and strain during its service life.

Criterion 2 - Elongation

When tested as outlined below the percent elongation of the flooring system shall not be less than 3% of its original length.

Test

The method of test shall be the same as outlined above. The percent elongation is calculated by dividing the elongation at the moment of rupture by the original length and multiplying by 100.

Commentary

The criterion was selected to ensure that the selected flooring systems are suitable for application in areas which may be subjected to dimensional changes or deformation.

5.3 Impact Resistance

Requirement

Flooring systems selected for use in high-traffic areas must withstand intentional abuse in addition to the accidental impacts that normally occur.

Criterion

When tested as outlined below, the flooring system shall not crack, chip or flake at an impact of 9.0 Joules.

Test

Impact resistance shall be determined as described in ASTM-D2794, Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). Triplicate specimens (100 mm x 100 mm) are taken from prepared steel panels (Type R, Q Panels, 0.875 mm x 150 mm x 300 mm, cold rolled, low carbon steel), and impacted with a 0.9070 kilogram cylindrical impact weight. The test is performed with the coated side up.

Commentary

Flooring systems such as vinyl tile are capable of withstanding impacts of 9.0 Joules. In view of the satisfactory performance of vinyl tile and solvent-thinned polyurethane systems, their performance was selected as the minimum criterion for impact.

5.4 Resistance to Indentation

Requirement

Flooring systems should be resistant to indentation by furniture, equipment and other heavy articles that are likely to be in contact with the floor for long periods of time.

Criterion

Flooring systems shall be free of visible indentation when a pressure of 1.3 megapascals is applied uniformly over an area of 6.5×10^{-4} m^2 for 5 minutes.

Test

Triplicate specimens are prepared by applying the system to 100 x 100 mm, solvent-cleaned, No. 21 Gauge cold-rolled steel according to the manufacturer's directions. After curing seven days at 23 ± 2°C and 50 ± 5% rh, the specimens are placed in a hydraulic press capable of indicating to the nearest 68,940 pascals. The cylinder against the finish shall be 6.5×10^{-4} m^2. The force shall be maintained for five minutes, the specimen removed and inspected for indentation.

Commentary

Flooring systems usually experience most severe indentation from furniture. Frequently, the design of furniture support legs result in the concentration of heavy loads in small areas of flooring. This criterion is to ensure that flooring systems are not marred by forces resulting from over-loaded furniture and appliances. Need for this criterion was frequently demonstrated in the field by indentations from tables, chairs and other appliances.

5.5 Dimensional Stability

Requirement

Flooring systems in high-traffic areas should remain functional and decorative when exposed to changes in temperature.

Criterion

When tested as outlined below, the average movement (flow) of triplicate specimens shall not be greater than 0.004 mm.

Test

Triplicate specimens are prepared by applying the system to 150 x 150 mm, solvent-cleaned, No. 21 gauge cold-rolled steel according to the manufacturer's directions. After curing seven days at 23 ± 2°C and 50 ± 5% rh, the specimens are scribed and placed vertically in an oven at 70°C for five hours. The difference in distance between the scribed mark and reference edge before and after heating is a measure of flow or slip. Measurements shall be made to the nearest 0.003 mm.

5.6 Resistance to Solar Radiation

Requirement

Flooring systems should retain their original appearance after expected exposure to solar radition.

Criterion

When the flooring system is subjected to solar radiation as outlined below, the change in color shall not be greater than 2 NBS units.

Test

Specimens are exposed to a xenon-arc radiant energy source in a weathering machine equipped with a constant wattage transformer to operate a 6500 watt water-cooled lamp. The lamp contains an outer and inner cylinder of borosilicate glass which filters out all wave lengths below 290 nanometers and above 1300 nanometers.

Triplicate specimens (100 mm x 100 mm) are taken from cured samples on plywood. The plywood (19 mm x 609 mm x 609 mm) conforms to Exterior AC Grade, Species Group I (Voluntary Produce Standard PS 1-74, American National Standard A1971-1974). After curing seven days, the color of each specimen is measured before exposure with a color difference meter. Specimens are exposed to solar radiation only, at a black box temperature of 67 $\pm$ 2°C. After 24 hours, the specimens are removed and stored at 23 $\pm$ 2°C and 50 $\pm$ 5% rh for two hours. Again, the color of each specimen is determined, and the color change calculated as specified in Method 6131 of Federal Test Method Standard 141a.

Commentary

This criterion was selected to ensure retention of the original appearance accepted by users of flooring systems. Flooring systems are generally exposed to solar radiation at windows, vestibules and door entrances.

5.7 Water Vapor Permeance

Requirement

Flooring system should be resistant to permeation by water and water vapor.

Criterion

Where flooring systems are required to be resistant to the transmission of water vapor, the glaze coat of the system shall not have a water vapor permeance greater than 4.6×10^{-11} kg/Pa·s·m^2.

Test

Triplicate specimens are prepared by application of the glaze coat to the highly permeable portion of penetration chart forms at a wet film thickness of 0.175 mm. The specimens are cured for seven days at 23 $\pm$ 2°C and 50 $\pm$ 5% rh.

A disc (100 mm in diameter) cut from the chart with the cured film is sealed over the mouth of a permeability cup containing 30 gms of calcium chloride and placed in an atmosphere of 23 ± 2°C and 50 ± 5% rh. The assembly is weighed once every 24 hours, and the results for the period in which the gain in weight is linear with time is used to calculate, in pascals, water vapor movement through the membrane.

Commentary

The sealing of moisture-laden flooring substrates by flooring systems of low permeability may cause cracking, flaking and peeling of the flooring system. The above criterion provides guidance in the selection of systems suitable for application to areas where the exclusion of water vapor is desired.

5.8 Resistance to Stain

Requirement

Flooring systems selected for use in high traffic areas should maintain their original appearance even after prolonged exposure to household materials.

Criterion

When tested as outlined below, the flooring system shall not wrinkle, blister or discolor.

Test

Stain resistance of the flooring system shall be determined as described in ASTM-D1308, Effect of Household Chemicals on Clear and Pigmented Organic Finishes. Glass vials (25.4 mm I.D., 12.7, height) are sealed to the surface of the flooring system with a polyurethane sealer. After twenty-four hours, 1 ml of coffee, mustard, tea, shoe polish and water are placed in separate sealed rings and covered with a watch glass. After sixteen hours the watch glasses are removed, the stains washed off and alteration to the flooring system noted.

Commentary

Flooring systems for use in high-traffic areas must resist attack by most common household stains. Systems that resist the action of such stains are likely to have longer useful service life and reduced maintenance costs. This criterion is intended to identify flooring systems which are able to resist common household stains. Performance of the system in the field demonstrated the need for a stringent requirement for stains in high-traffic areas.

5.9 Flame Spread

Requirement

Flooring systems shall provide resistance to the spread of fire.

Criterion

When tested as outlined below, the flame spread index shall not be greater than 200.

Test

The method of test shall be in accordance with the procedure specified in ASTM E-84.

Commentary

This criterion is intended to provide the user a surface finish resistant to the spread of fire. The criterion is in accordance with the HUD Minimum Property Standards (MPS) [9] within the living unit except for the kitchen space. Areas where exposure to fire are more likely, and exit areas, where the degree of resistance to fire may determine the time that the occupants of a building have to leave a residence, usually have more strict flame spread requirements.

5.10 Smoke Generation

Requirement

If in a fire, flooring systems should not yield specific optical densities of smoke and combustion product levels of gaseous components which are hazardous to occupants of buildings.

Criterion

When tested as outlined below, materials that yield combustion product levels greater than the upper limits listed by Gross et.al. [10], given below, shall be classified as "potentially hazardous".

Hazardous Combustion Product Levels[10]

	Concentration in PPM
a. CO	10,000
b. HCl	1,000 - 2,000
c. HCN	200 - 300
d. $NO + NO_2$	200

Test

The method of test shall be as described in NBS TN 708, "Interlaboratory Evaluation of the Smoke Density Chamber Test Method", Appendix II, by T.G. Lee, December 1971 [7].

Commentary

The above levels were based on a short term exposure period. These levels represent a potential danger to life when exposed 2 to 5 minutes.

Acknowledgement

Acknowledgement is gratefully extended to the local housing authorities at the 20 sites and to their staff without whose patience, cooperation, and advice the field demonstration could not have been conducted.

We thank George Erickson of the Department of Housing and Urban Development for his contribution in locating the 20 field demonstration sites and for making initial contacts with each of the responsible housing authorities.

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APPENDIX A

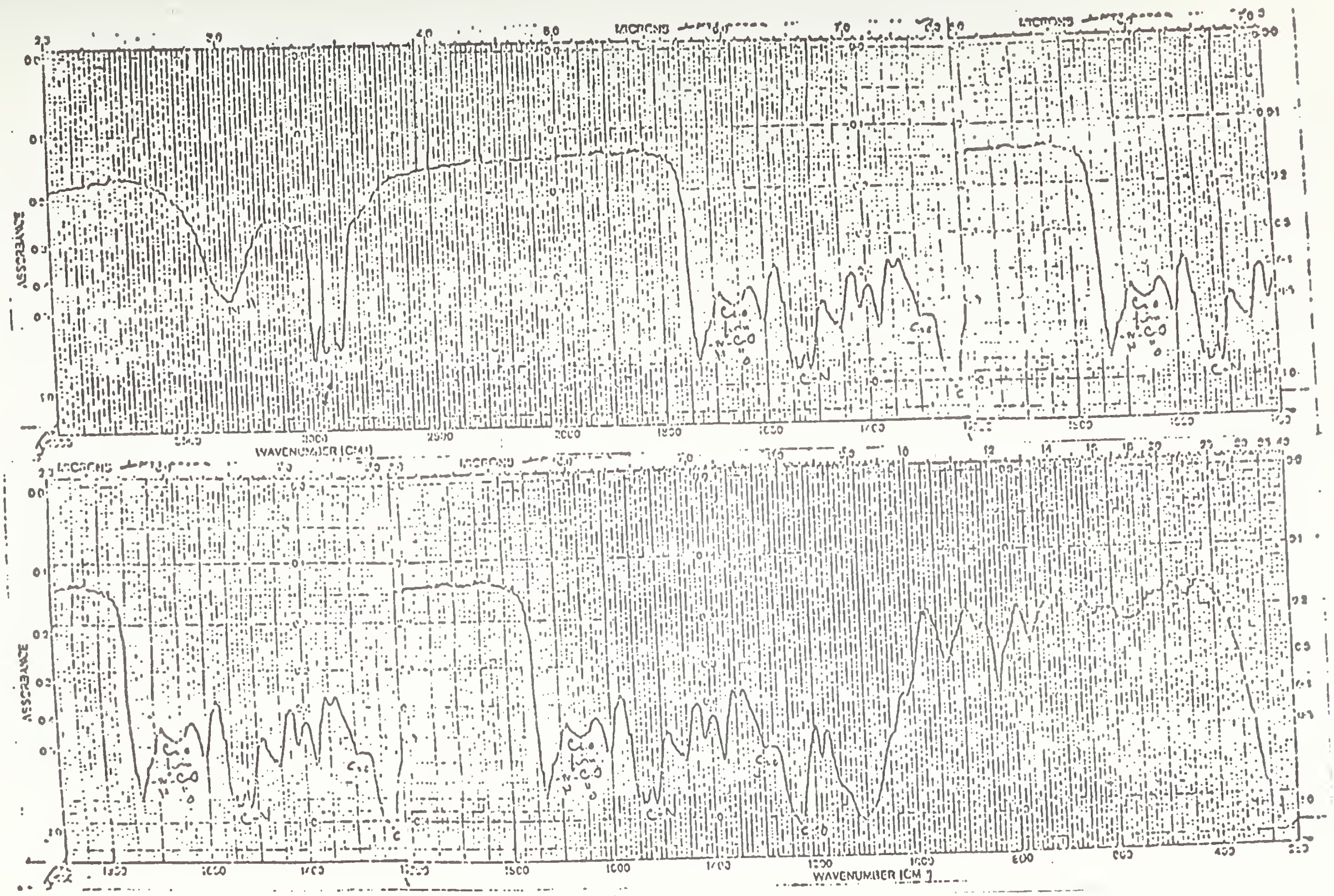

Figure 1 Infrared Spectrum of the Glaze Coat of the Water-Thinned Polyurethane System.

APPENDIX B

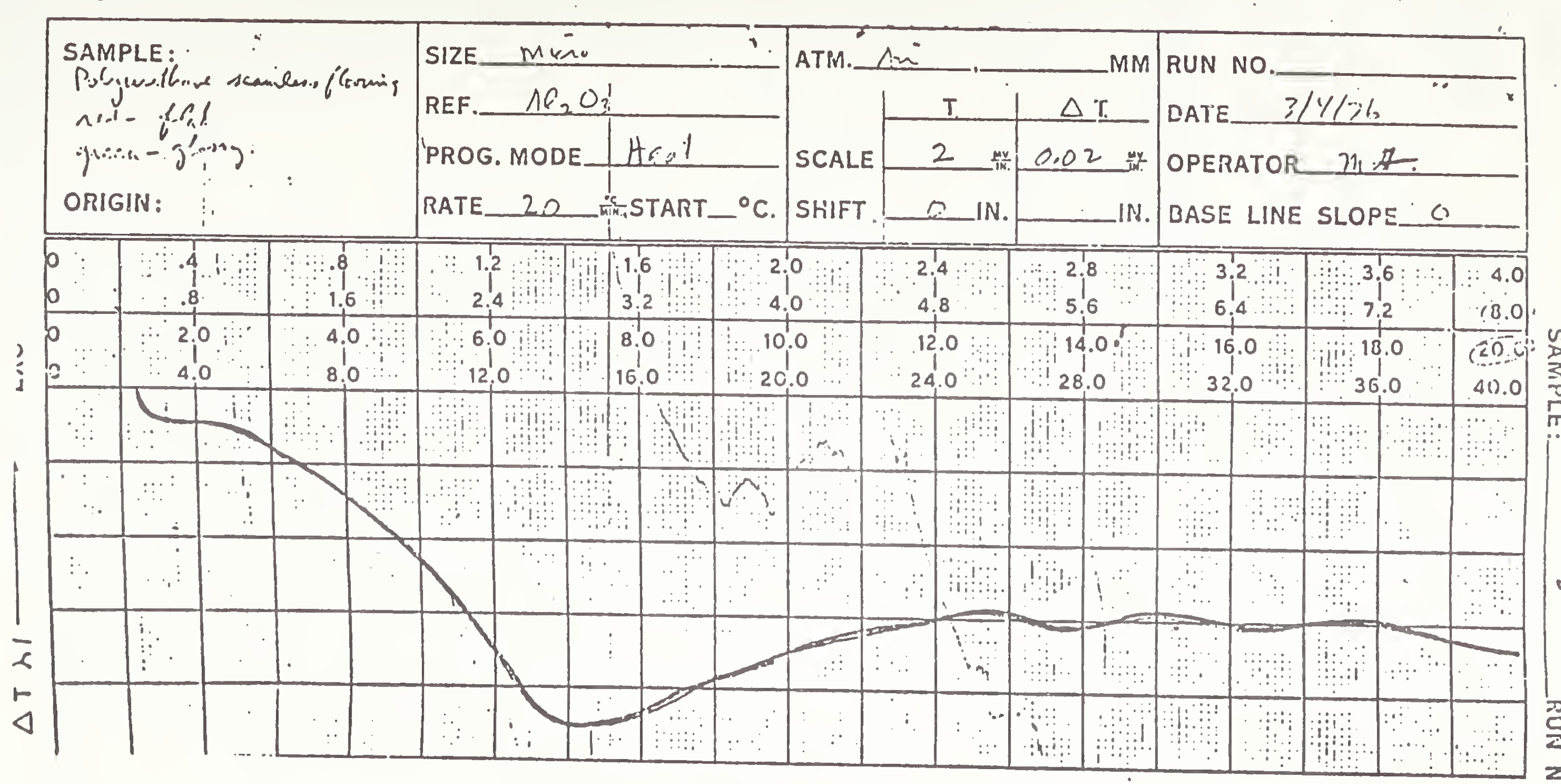

Figure 1 Time-Based Thermogram of the Water-Thinned Polyurethane Seamless Flooring System

APPENDIX C

Manufacturer's Approved Application Method

1. Introduction. If the applicator has complied with the recommendations outlined in Chapter 3*, Job Set-Up, and Chapter 4, Surface Preparation, he is now ready for installation of the system in a well lighted and adequately ventilated area. The substrate is thoroughly cleaned, and adjacent areas prepared for the installation of the system.

2. Application of Base Coat

   a. The first step in the installation of the system is the application of the base coat. This material is a two-component emulsion epoxy. The purpose of this material is to "weld" the system to the substrate, establish a background color, and act as a barrier coat to block off the possible bleed-through of any latent contamination in the substrate. Reference should be made to Figure 2*, the chart, to ascertain the amount of material to mix. You will note that the containers are marked with appropriate nomenclature and are also marked "A" and "B". Be sure that the materials in both containers are thoroughly mixed prior to measurement of the amount needed for the installation. Equal parts of A and B should be mixed together to achieve the total gallonage required. Do not mix more material than can be easily applied within one hour. The emulsion is manufacturered with one component white and one component with a bluish tint. This is designed to help the applicator see that the components are thoroughly mixed. If the base coat is to be tinted to match a predominant flake color, the first coat of base coat should be applied as received and the second base coat applied at the color desired. This will aid in making sure that all areas have the minimum of two base coats.

*For complete details see reference [8].

b. A Universal tint or colorant must be used to achieve color and only colorants supplied or recommended by the material manufacturer should be used in the base coat. It is a wise precaution to disperse the colorant in a small container of water prior to adding the tint, being sure that the materials are again well blended to disperse the colorant so that you will not have streaks in the applied coating. A powered mixer is helpful. These are available with propellers mounted on various length shafts that fit into standard electric drills.

c. Plastic containers are preferable, as they are economical and easily cleaned. They may be used over and over again.

d. If the base coat is to be sprayed, request specific instructions from the manufacturer. Follow the manufacturer's recommendations closely and beware of "dry spray", as this will often happen when spraying a floor area. Dry spray may be caused by atomizing pressure that is too great, but may also be caused by fanning at irregular distances and by holding the gun too far from the substrate. This is frequently done on floor jobs, due to the nature of the work. The applicator is advised to exercise caution in this respect.

e. When the application is by roller, a medium nap paint roller will suffice, and cut-in may be by brush. For ease of application, potable water may be added to the mixed material. This should never exceed 6% by volume of the entire mix. The material should be worked into the substrate by pressure on the brush or roller and adequate coverage made to insure hiding and an even film over the substrate. Any material left over should be discarded.

3. Second Base Coat. With proper ventilation and heat, the installation should be ready for the second base coat within an hour, following the same procedure as described above. Tinting should be done as closely as possible to the desired shade. From this point on, the applicator should use cleated shoes or booties (with the former preferable) to avoid transmitting contamination to the dry but not cured coating. Following the procedures outlined above, apply the second base coat in as even a film as possible. When completed, the entire area should have two full coats of base and be of an even color.

4. Decorative Flakes. While the second base coat is drying (or before starting the application), the decorative flakes should be mixed to the desired mixture or pattern. This may be achieved either by weight or by volume, the latter being the more prevalent method. If a blend, as an example, calls for four parts beige, two parts white, and one part brown, this may be weighed or measured in drums, buckets, cups, or any available container. Bear in mind that one pound of flakes will finish 0.9 to 1.3 square meter of floor area, but that at least 25% more flakes will be needed to achieve the desired effect. The surplus flakes may be used again on other installations. Mix the flakes well and have them adjacent to the installation area. Gallon-size buckets make excellent containers for broadcasting flakes into the wet material. Be sure to note on your records the ratio of colored flakes mixed, as you may need this information at a later date.

5. Chip-In Urethane Coat

   a. After the second base coat is thoroughly dry, you are now ready to apply the chip-in urethane coat. The prime purpose of this coating is to receive the decorative flakes and weld them into a smooth esthetically acceptable monolithic film. This material is a one-component urethane emulsion that is milky in appearance, but will dry into a

clear film. When this material, into which you will distribute or broadcast the mixed flakes, is applied in an exceedingly thin film in some areas and in near puddles in others, each section would hold or retain flakes in proportion to the amount or thickness of the coating. This would cause the finished surface to end up with a splotchy or uneven color. It is, therefore, important that the first coat of chip-in urethane be applied in as even a film as possible.

b. If the application is by spray, follow the suggestions given previously in regard to the spraying of the base coat.

c. Medium to short nap roller covers should be used to apply the chip-in urethane coat. An acceptable brush will suffice for cutting in the edges and to coat hard-to-reach areas. Be sure that you brush on the same amount of material as will be rolled on so that your colors will be even and uniform throughout the job. Your cleated shoes will now prove their worth and allow you to walk on the freshly applied coating. After cutting in by brush, roll on the chip-in urethane coat as evenly as possible and then cross roll the area. This rolling at 90° to the initial roll will help you maintain an even coat devoid of puddles and roller edge marks. Do not press hard on the roller when cross rolling, and do not coat more area than you can effectively cover with flakes while the urethane chip-in coat is wet and receptive. Power devices are available for the broadcasting of flakes; but distribution by hand is very satisfactory, and remains the most widely used method. Distribute the flakes as evenly as possible over the substrate, making sure to have no voids or holidays. Oblique lighting will show up areas too lightly covered with flakes by reflecting the

lights or showing "shiny" areas. Cover one area completely before moving to another, and always leave 100 to 150 millimeters of wet edge without flakes so that when you coat the adjoining area with the chip-in urethane coat, you can tie in the areas. Occasional flakes will fall into the wet area, and the advantage of the clear chip-in urethane coat will be readily apparent when you "freshen up" the wet edge. You may now go directly over the flakes scattered into the wet material and upon the edge of the fully chipped area without destroying the esthetics. If flaking into a colored coating, this would not be possible, as streaks would possibly occur in the floor. When broadcasting the flakes, fine particles settle to the bottom of the container. Be sure not to put these into one small area, but sprinkle these small particles over a large area, preferably an area already chipped with the larger flakes.

d. <u>With proper ventilation and heat</u>, the urethane chip-in coat should be sufficiently dry within an hour to continue the operation. Sweep the floor surface with a clean stiff-bristled broom to remove excess particles, paying particular attention to corners and hard-to-reach areas where there may be an accumulation of flakes. Follow this procedure with a thorough vacuuming of the area. Check the wheels of your vacuum cleaner to be sure you do not bring contamination into the installation.

e. <u>While waiting for the chip-in urethane coat to dry</u>, it would be a good time to clean up tools and equipment that will no longer be needed on the job. Brooms, vacuum cleaners, flakes, etc., will no longer be required. Application tools may be cleaned (see Figure 2, the chart, under "Clean-up" for method of cleaning) and stored for future use, and the entire installation readied for application of the glaze coats.

6. Final Coats

a. The final coats to be applied are referred to as glaze top coats and are consecutive coats of the same water dispersed urethane used as the chip-in coat. This material is a one-component urethane emulsion that is milky in appearance but will dry into a perfectly clear, tough, durable film with a velvet finish that will effectively resist abrasion.

b. Refer to Chapter 3,* Job Set-Up to be sure you have located your fans and lights correctly, as it is most important at this stage of the installation. Consult Figure 2, the chart, referring to coverage data on the water dispersed urethane glaze coat. Bear in mind that you must now exercise care as the glaze will magnify greatly any foreign substance. The applicator is further cautioned that the glaze must never be allowed to accumulate into a thicker film than that achieved by rolling the material on with a short nap roller. If this material is to be sprayed, follow manufacturer's recommendations closely and pay particular heed to instructions. Apply approximately 0.064 millimeters of dry film.

c. Start of application (coatings system). Upon start of application, cut in with a brush and apply the glaze by the roller in an even film over a small area. Do not work the roller any more than necessary, and cross roll lightly to be sure of even distribution. When completed, flush your roller and brush thoroughly with water and dry with clear, absorbent cloth on paper. They will now be in good condition for your next coat.

*For complete details see reference 8.

For best results use a new white short nap roller with a long-handled applicator. The use of a colored roller is not recommended as the color may bleed out.

The urethane glaze is used as received. Nothing need be or should be added. Pour a line of urethane glaze across the <u>width</u> of the application area and roll in one direction to cover the area completely. Apply at a rate of approximately 23.2 to 27.9 square meters per gallon. Pour additional glaze as necessary until the area is completely glazed. Apply the glaze as thinly as in painting but be sure to cover the entire area, especially the edges. The use of a paint brush may be necessary at edges and in corners.

Allow the first coat to dry until tack free, approximately 1/2 hour. The second coat may be applied as soon as the first coat is dry enough to walk on using plastic <u>footwear</u> or plastic bags over your feet. A slight elasticity is normal but no footprints will remain if the glaze has adequately dried.

Apply the second coat of urethane glaze along the <u>length</u> of the application area, at right angles to the direction of the first coat. Roll out the second coat in one direction filling in and evening streaking in the first coat.

Allow the second coat to dry until track free.

Apply the third coat of glaze at right angles to the second coat, etc.

d. Subsequent coats may be applied as soon as the preceding coat is completely dry to the touch. A minimum of three glaze coats is recommended. These coats impart the wearing quality of the seamless coating.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 77-1399	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Performance of a Water-thinned Polyurethane Seamless Flooring System			5. Publication Date December 1977
			6. Performing Organization Code
7. AUTHOR(S) M. Godette, Paul G. Campbell			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Division of Energy Building Technology and Standards Office of Policy Development and Research Department of Housing and Urban Development Washington, D. C. 20410			13. Type of Report & Period Covered Final
			14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This paper summarizes the work of a two-year project to evaluate the performance of a water-thinned polyurethane seamless flooring system. The goals of this project included: 1) To evaluate by laboratory tests and field demonstrations the performance and durability characteristics of a water-thinned polyurethane seamless flooring system; 2) To compare the performance of a water-thinned polyurethane system with solvent-thinned polyurethane systems and other conventional flooring materials; and 3) To recommend performance criteria for the selection of water-thinned polyurethane seamless flooring systems.

The project was divided into two phases, laboratory evaluation and field demonstration. Data obtained from local maintenance engineers at the 20 demonstration sites confirmed laboratory findings that the system did not compare favorably with conventional flooring systems for use in high traffic areas.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Water-thinned polyurethane system; solvent-thinned polyurethane system; vinyl tile; laboratory findings; field demonstration; maintenance engineers; service conditions; high traffic areas.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[x] Unlimited [ ] For Official Distribution. Do Not Release to NTIS [ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [x] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	78
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $6.00

USCOMM-DC 29042-P74